

## **Beaked Whale Group Deep Dive Behavior from Passive Acoustic Monitoring**

Jessica A. Shaffer and Paul Baggenstoss  
1176 Howell St.  
Newport, RI 02879  
phone: (401) 832-5317 email: [jessica.a.shaffer@navy.mil](mailto:jessica.a.shaffer@navy.mil)

Diane Claridge & Charlotte Dunn  
Bahamas Marine Mammal Research Organisation  
P.O. Box AB-20714  
Marsh Harbour  
Abaco, Bahamas

Tiago Marques & Len Thomas  
Centre for Research into Ecological and Environmental Modelling  
University of St Andrews

Award Number: N0001415WX01383 / N000141512648 / N000141512649

### **LONG-TERM GOALS**

While a significant body of knowledge regarding individual beaked whale behavior at depth has been established in the last decade, little is known about how beaked whales interact as a group at depth. This lack of information makes it difficult to interpret the results of animal exposures to anthropogenic noise, and their impact on long term foraging success and population health. The objective of this study is to provide novel information on beaked whale group foraging dive behavior using Passive Acoustic Monitoring (PAM) at the Atlantic Undersea Test and Evaluation Center (AUTC). Blainville's beaked whales, *Mesoplodon densirostris* (Md), are routinely detected year-round on the AUTC range, coincident with routine use of Navy sonar. By tracking individual whales within group foraging dives, a more complete understanding of group foraging strategy at depth will be obtained, including: prey capture attempts, spatial relationships among conspecifics, independent or cooperative prey hunting, and foraging strategy. This information will be used to create a statistical model of beaked whale group deep dive behavior including behavioral dynamics of individuals within the group and group foraging strategy.

### **OBJECTIVES**

1. Create a new detection, classification and localization method capable of utilizing passive acoustic data from the hydrophone array at AUTC to track individual clicking beaked whales within group deep dives. By tracking individual whales within a group foraging dive we will be able to evaluate group foraging strategy at depth including: prey capture attempts, spatial relationships among conspecifics, independent or cooperative prey hunting, and foraging strategy.

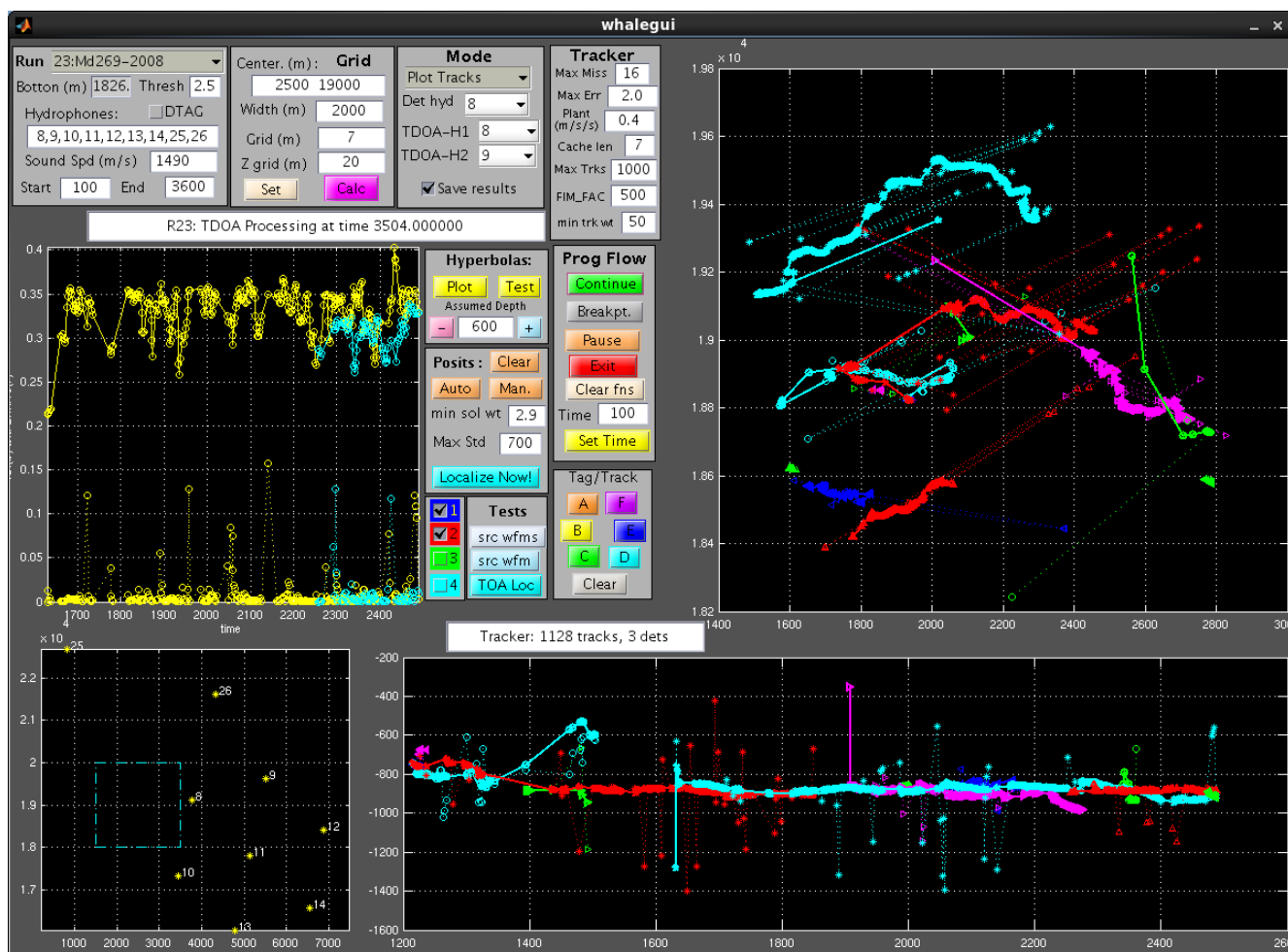
2. Create a model relating acoustic footprint statistics (e.g., click detection counts, number of hydrophones detected, etc.) on hydrophones to group size and parameterize it using surface visual observations. The statistical model will also enable development of a real-time algorithm to estimate and display group size information for support of future tagging or other field experiments, as well as the possibility for routine density estimation based on dive counting.
3. Create a statistical model of beaked whale group deep dive behavior using the results of (1) and (2). The model will include behavioral dynamics of individuals within the group, group foraging strategy, habitat preferences, and reaction to surface ship sonar (e.g., Moretti *et al.*, 2014).

## **APPROACH**

We enhanced a novel method of Detection, Classification and Localization (DCL) developed under the ONR Advanced DCL program to provide the ability to DCL beaked whale clicks from multiple individuals within a diving group (Baggenstoss, 2013). Automatically tracking the whales requires overcoming several hurdles. One of the problems is the large number of ambiguous solutions. These ambiguities come from two sources. First, false time-delay measurements arise when the time difference-of-arrival (TDOA) is measured between clicks or click-trains from different sources, different propagation paths, or different periods of a given periodic click-train. Second, even if the TDOA measurements are valid and correctly associated, the localization solution might be ambiguous due to the fundamental geometry. We propose to develop a multi-hypothesis tracker (MHT) that carries thousands of simultaneous track hypotheses, called particles, each updated according to a conventional Kalman filter algorithm that develops a speed estimate by processing point estimates over time (see Publications: Baggenstoss, 2015 for details).

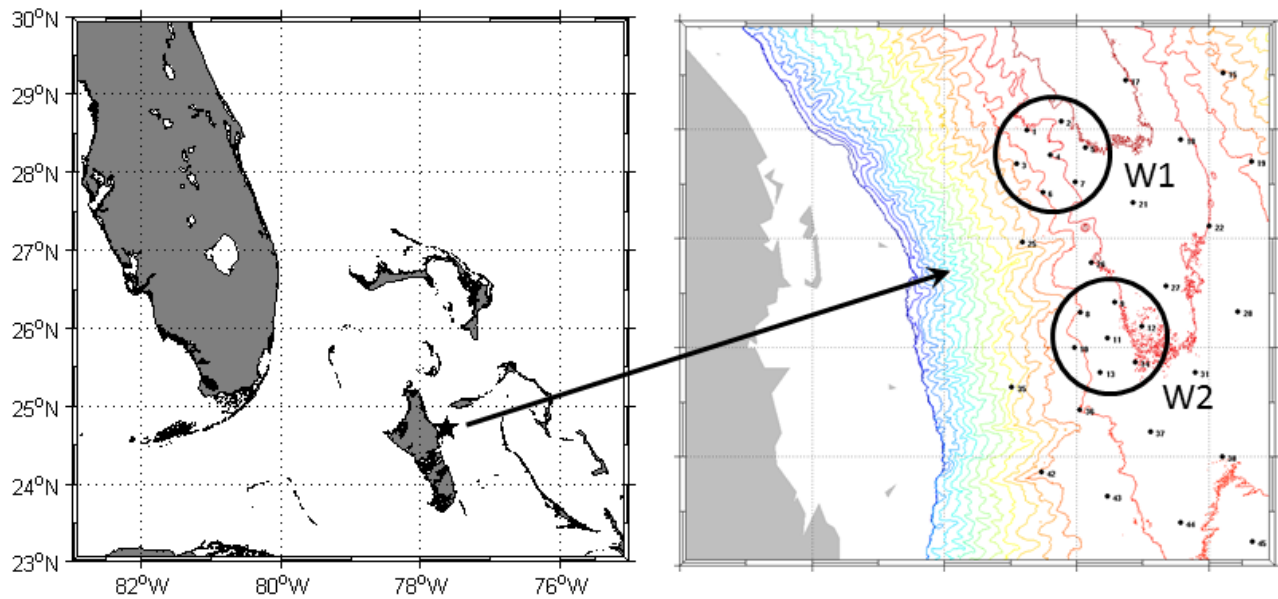
## **WORK COMPLETED**

The preliminary software package was modified to include a multihypothesis tracker. A Graphic User Interface (GUI) for detection, classification, localization and tracking (DCLT) of individual whales was created using Matlab (Mathworks) (Figure 1). The GUI enables simplified processing of time synchronized audio wav-format recordings from AUTECH hydrophone arrays. The GUI provides options for manual verification and automated processing. This enables the user to fine-tune parameters to the array geometry for each dive prior to proceeding with automated DCLT. For example, the detection threshold can be increased in the presence of noise or decreased for animals distant from the array. The minimum solution weight and minimum track weight, which relate to the quality of an individual localization and an individual track, can also be adjusted dependent on the geometry of the group to the array. The program loops through each hydrophone in the array detecting and classifying beaked whale foraging clicks within a 2 second window. These new detections, in addition to the previous 10 second detection history, are used to localize whales within the current 2 second window. The mean interclick-interval, detection history, error estimate, quality measure, and other detailed processing information specific to each localization is saved for every 2 second window.



**Figure 1. Beaked Whale Detection, Classification, Localization and Tracking Graphical User Interface**

The AUTECH range consists of a large area 2-nmi baseline array and two adjacent smaller 1-nmi baseline hydrophone arrays (Figure 2). This study focuses on the two 1 nmi-baseline seven hydrophone arrays, 'W1' and 'W2'. The shorter baseline provides an increased probability of detecting clicks from an individual whale on multiple hydrophones, a necessity for three-dimensional localization. Broad-band audio recordings of all 91 hydrophones have been collected during test events at AUTECH since 2005. Recordings were made using a bank of time synchronized Alesis HD24 recorders. Simultaneous detection and classification records were also stored from the Marine Mammal Monitoring on Navy Ranges real-time DCL systems. These detection records were used with several existing M3R software modules "ClickTrainProcessor" and "Autogrouper" to quickly identify start and end times of groups of vocalizing beaked whales on the W1 and W2 arrays. Group vocalization start and end times were used to extract audio wav files corresponding to the appropriate hydrophones and corresponding IRIG time track from the Alesis recorders, a simple but time intensive process. The IRIG time track is used to obtain a precise start time for each audio wav file. Sixteen of these high priority groups have been processed through the DCLT GUI. In addition, ten groups with visual verification of group size from 2005-2008 were also processed. The visually verified groups occurred throughout the range, with the majority within the 2-nmi baseline array area.



**Figure 2.** *The AUTECH study area located west of Andros Island with an inset showing the Whiskey 1 (W1) and Whiskey 2 (W2) 1-nmi baseline hydrophones arrays.*

Approximately 415 hours of detection archives were reviewed for the presence of beaked whale foraging groups between 31 August and 1 October 2008. Seventy-four groups of beaked whales were detected at least partially over the W1 and W2 arrays. Fifty-four of these are of high-interest, a designation given to groups that appear to be within or very close to the array based on click detections on individual hydrophones. Of these, seventeen beaked whale group deep dives on the W1 and W2 arrays and an additional ten visually verified dives were processed through the DCLT GUI, for a total of 27 dives.

The resulting tracks from each dive were evaluated and categorically assigned the designation of (1) high, (2) moderate or (3) low quality. High quality (1) tracks require minimal manual splicing of track segments, have few/no unassigned track segments (short track segments that appear real but don't obviously connect to any of the more obvious tracks), and clearly indicate the number of whales in the group. Moderate quality (2) tracks require manual splicing of multiple track segments, often contain unassignable track segments in which it is unclear which whale a particular track segment belongs to, or more often contain one high quality track from an individual with good array geometry and an assortment of unassignable track segments from other whales in the group. Low quality (3) tracks typically consist of a high number of short track segments that are not obviously connected in space or time. This typically occurs when a group is localized outside the boundary of the array. As the animals turn toward the array, track segments are created, but when they turn away no localizations are available.

A preliminary summary of *Md* group deep dive behavior was created for all dives identified as having high quality tracks. Dive click start and end times, descent time, and foraging time/depth were determined for each individual. Distance between animals, travel direction, residence index, horizontal and vertical speed were calculated for each 2-second interval. Click time-of-emission for each whale was also back-calculated using the hydrophone time-of-arrival data from which each track was formed. From DTag data, we know that *Md* acoustic foraging behavior consists of three phases: search,

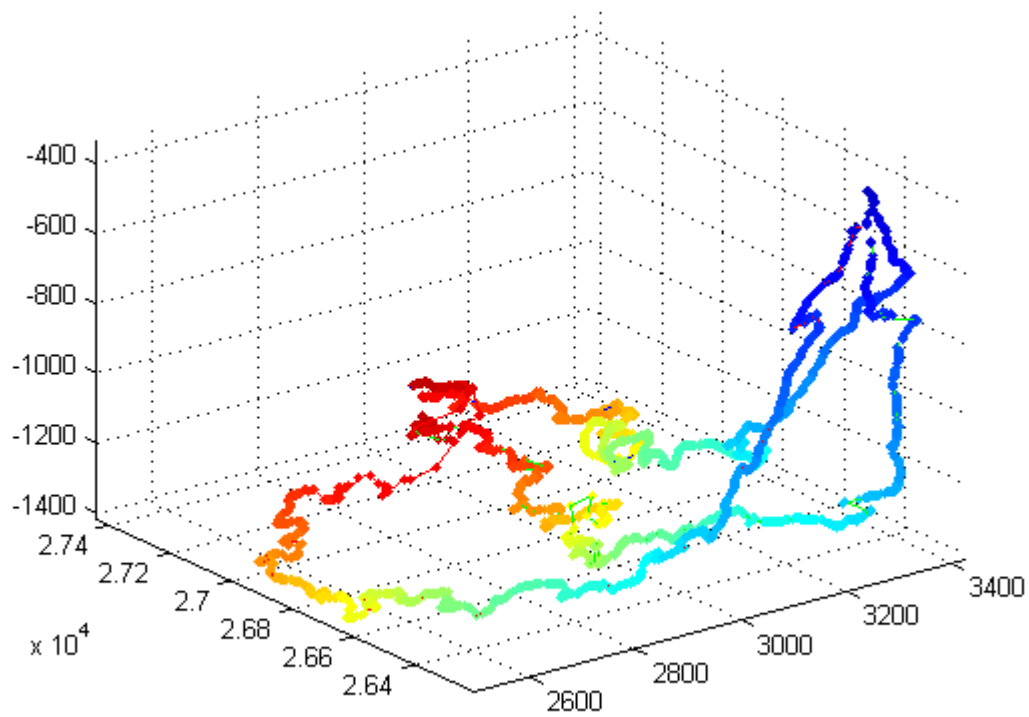
approach and terminal (Madsen et al., 2005). During the search and approach phases, *Md* produce regular clicks with an ICI of 300 to 400 ms, with no apparent change in ICI as the whale approaches its target (Madsen et al., 2005). The terminal phase is a buzz, defined by very rapid 5-20 ms ICI lower source level clicks as the animal intercepts the target, that lasts 2-5 seconds (Madsen et al., 2005). Preliminary evaluation of the reconstructed click trains for each whale indicates that while the buzzes are not normally detected, the 2-5 s pause in regular foraging clicks is, and occurs at a rate indicative of buzzes. The pause is often followed by an ICI of less than 0.25 s prior to resuming the search/approach phase regular ICI rate. As a preliminary proxy for buzzes, 'buzz-like' pauses of 2-6 seconds immediately followed by a short ICI click of less than 0.25 seconds were identified. Additional AUTECH DTag data needs to be evaluated to further refine this criteria.

## RESULTS

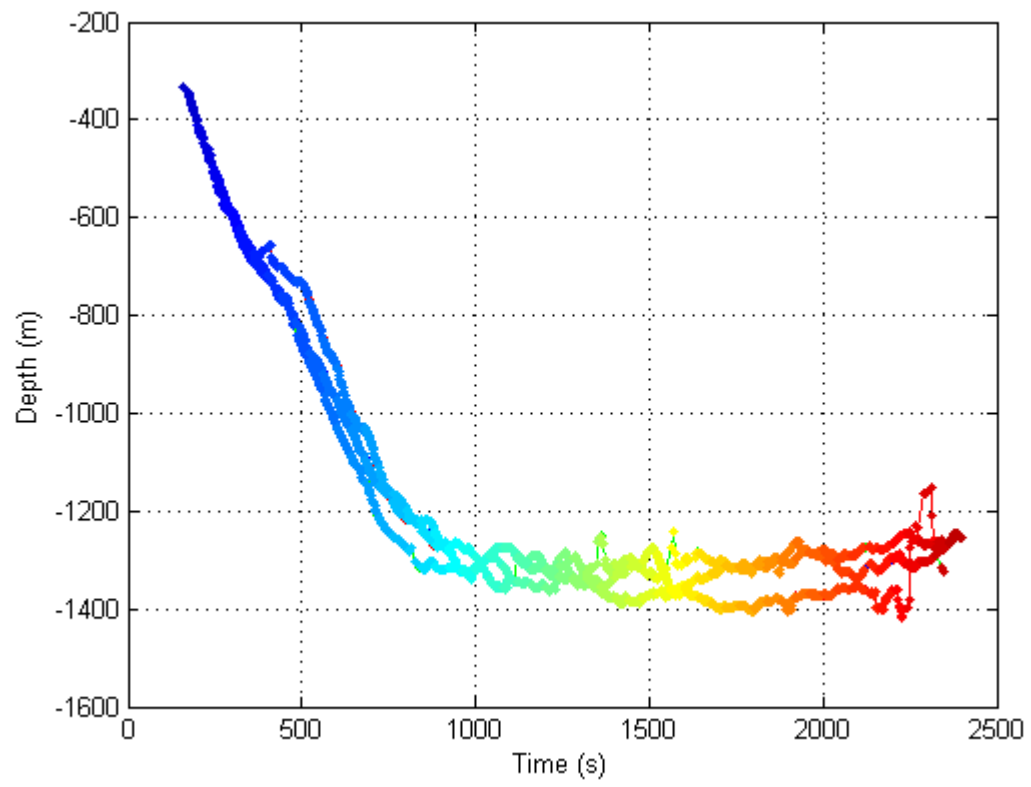
High quality group tracks were present for nine of the 27 dives evaluated thus far. An additional nine dives had moderate quality tracks where perhaps one animal's complete dive was tracked but the remaining animals had incomplete tracks. Of the nine high quality groups, there were two groups consisting of a single animal, two groups of two animals and five groups of three animals.

This study has obtained novel information on deep dive foraging behaviors of *Md* conspecifics within a group (Figures 3-7). In all cases, one animal initiated clicking, followed by conspecifics in the group on average 3 minutes later (range 4 – 508 sec). Most often, the entire group was foraging at roughly the same depth, although on two occasions individuals within the same group were separated by 200 m in depth. The animals foraged at a mean depth of 1070 m (range 760 - 1360 m, n=28) for on average 18 min and up to 28 min. Including the portion of the descent when the animal was clicking, the entire 'vocal' duration of the dive was approximately 26 min (range 13 - 37 m, n=28). The mean number of foraging clicks emitted and detected by each animal was 3122 clicks per dive (range 939 – 6663 clicks). The number of 'buzz-like' pauses identified was primarily related to the length of the dive at foraging depth (Figure 8). The mean 'buzz-like' pause duration was 2.7 sec (range 2.2 – 3.3 sec).

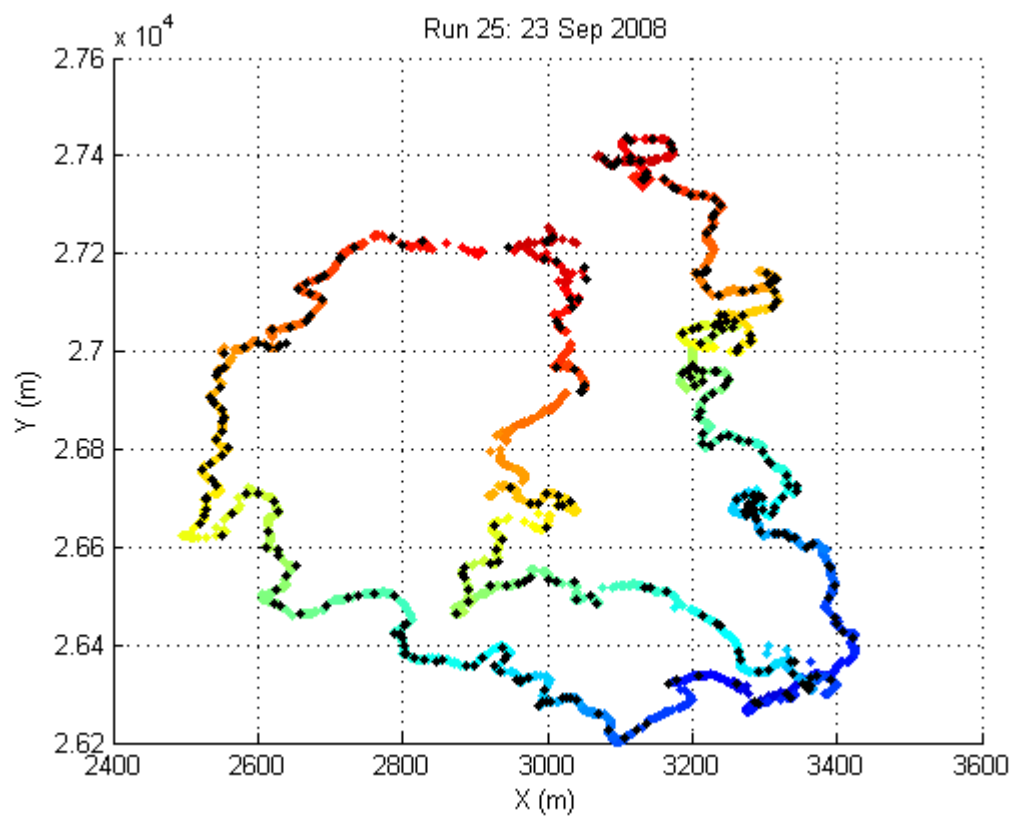
The preliminary results of this study suggest that when in group of three, the animals dive together and separate underwater, while in smaller groups of two the animals stay closer together. During FY16, these patterns and the behavior implications will be further evaluated to provide new insight into *Md* deep dive behavior.



***Figure 3. A three animal group foraging dive on 23 September 2008 0124 GMT. Color indicates the progression in time through the dive with clicking initiating (dark blue) and terminating at depth (red).***

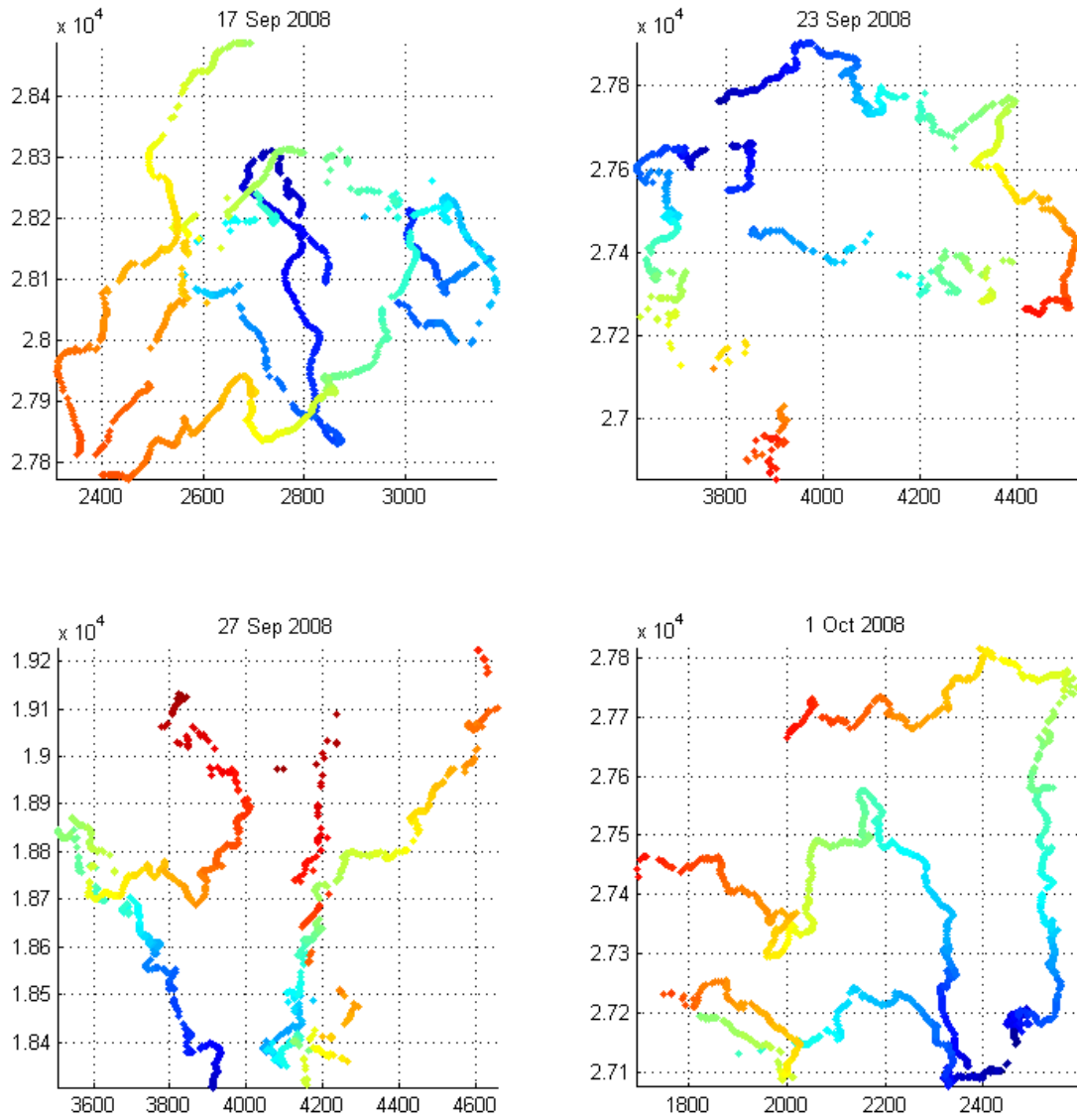


***Figure 4. Dive depth profiles for the group in Figure 3.***

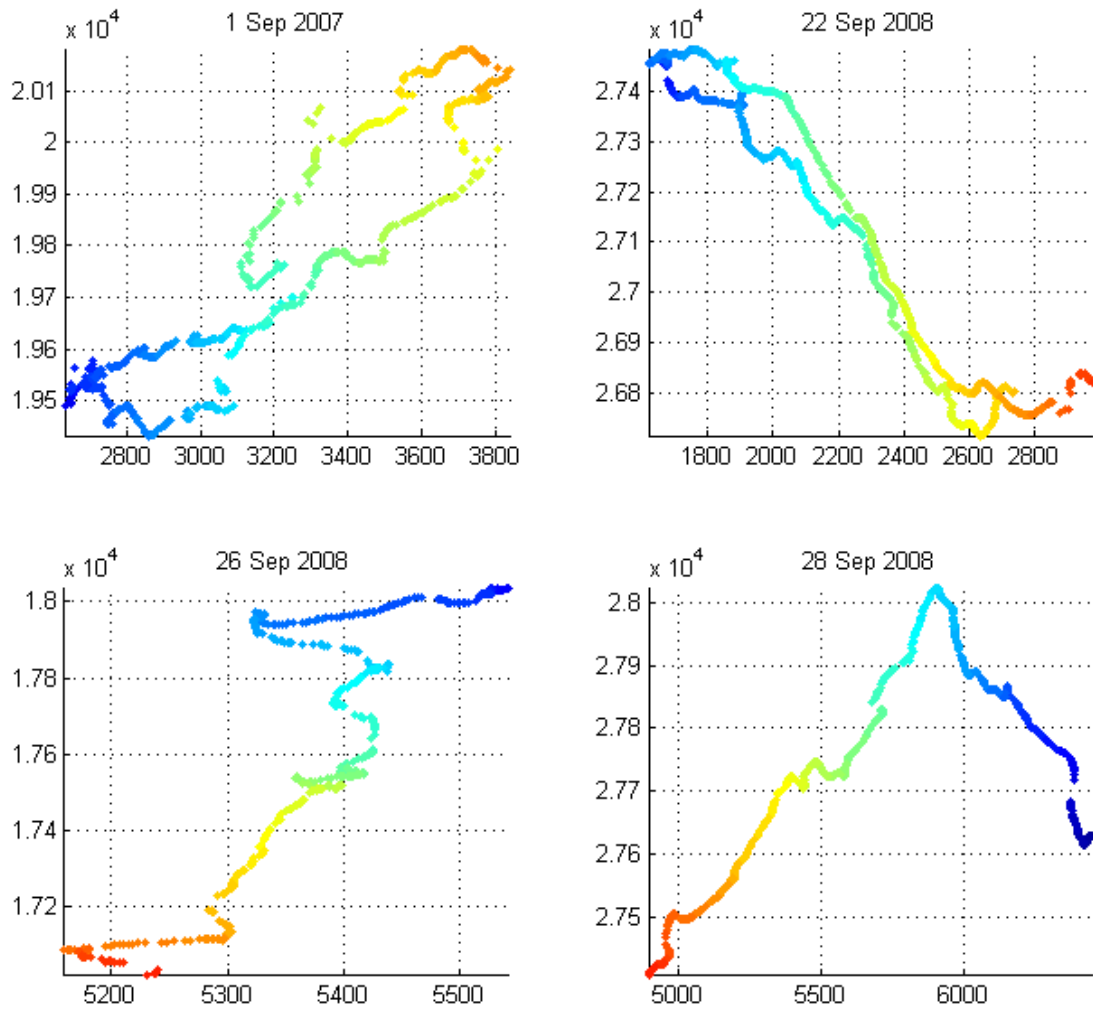


*Figure 5. XY plot of group in Figure 3 with the occurrence of ‘buzz-like’ pauses noted in black.*

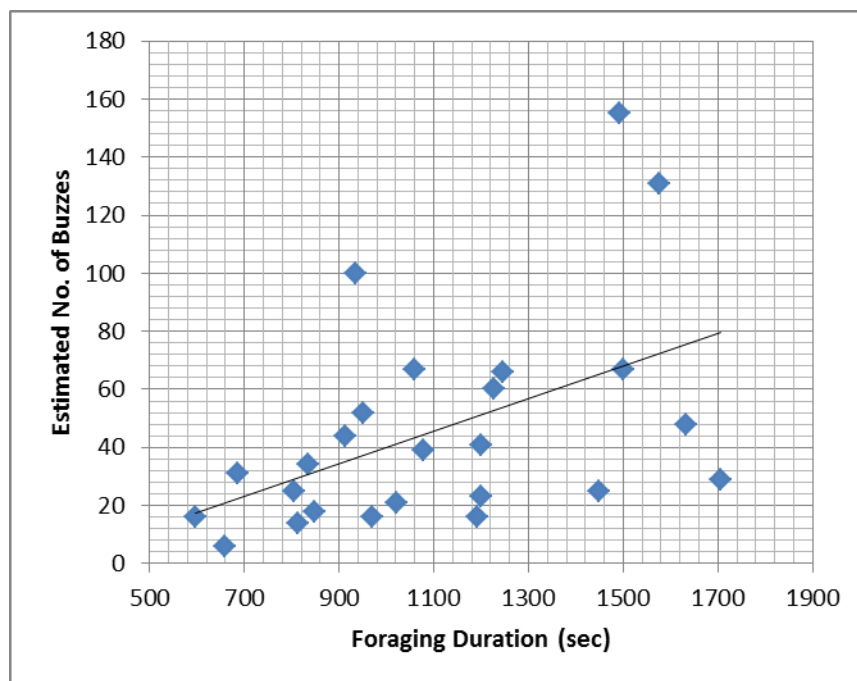




**Figure 6.** XY plots of four additional 3-animal groups. Color indicates the progression in time through the dive with clicking initiating (dark blue) and terminating (red).



**Figure 7. XY plots of four groups of size two animals (above) and a single animal (below). Color indicates the progression in time through the dive with clicking initiating (dark blue) and terminating (red).**



**Figure 8.** *Estimated number of ‘buzz-like’ pauses identified per animal vs the duration at foraging depth.*

## IMPACT/APPLICATIONS

The group behavior data observed in this study will be used to create a statistical model of beaked whale deep dive foraging behavior. Beaked whale group behavior at depth was previously unknown. This will assist in better understanding the impact of underwater sound on the beaked whale population.

## RELATED PROJECTS

Marine Mammal Monitoring on Navy Ranges – This study is using data collected by this program since 2005.

In-house Laboratory Innovative Research – This program is building on initial work performed by a complimentary NUWC ILIR to develop and demonstrate the ability to track individual whales within a group foraging dive.

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Moretti, D., Thomas, L., Marques, T., Harwood, J., Dilley, A., Neales, B., & Morrissey, R. (2014). A risk function for behavioral disruption of Blainville's beaked whales (*Mesoplodon densirostris*) from Mid-Frequency Active Sonar. PloS one, 9(1), e85064.

## **PUBLICATIONS**

Baggenstoss, Paul M. (2015) "A multi-hypothesis tracker for clicking whales." *The Journal of the Acoustical Society of America* 137.5: 2552-2562.